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Map 0L systems with markers

by

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0. Introduction

Recently, there have been published a number of interesting papers on map generating systems. (For example, see papers in [1] and [2].) They also include the cell division systems which are motivated from a biological point of view.

A map is defined combinatorially by Tutte [3].

In [4], we proposed two map generating systems based on string generation. The first one is binary, propagating map 0L system with makers (mBPM0L systems). The second one is binary, propagating map 1L system with makers (mBPM1L systems). Then, we consider the following decision problems (1) and (2) on these systems:

- (1) Whether or not an arbitrary mBPM0L system is deterministic ?
 - (2) Whether or not an arbitrary mBPM1L system is deterministic ?
- These decision problems were solved in the paper [4]. Also, in

the same paper the decision problem of stability of these two systems was solved. It is not so difficult to show that the membership problem of propagating systems is recursively solvable.

In this paper, we shall consider an extension of binary, propagating map OL systems with makers. We propose map OL systems with makers (mMOL systems). The systems are nondeterministic, and also neither binary nor propagating. Then, we shall examine the membership problem of the mMOL systems. As an interesting result, we show that this decision problem is recursively unsolvable. The main purpose of this paper is to prove this fact.

We assume that readers are familiar with the basic definitions and notations of map generating systems.

1. Definitions

We give here some definitions and notations. They are almost the same to those of [4].

Definition 1.1 A binary, propagating map OL system with makers (mBPMOL system) is a quadruple $(\Sigma, \{\downarrow, \uparrow, +, -, (,)\}, P, S)$, where

- (1) Σ is a finite edge alphabet,
- (2) P is a finite set of edge productions,
- (3) S is a starting map:

Here, edge productions are of the form $A \rightarrow a$, where A is a member of Σ (an edge label) and a is a sequence of members of Σ and signs $+$, $-$, and of markers \downarrow , \uparrow and matched parentheses. In this case, only one symbol appears within a closed parentheses. For instance, the rewriting of an edge represented in Figure 1 is written as the edge production:

$$A \rightarrow D^+C^- \downarrow (E^-)B^+.$$

The makers \downarrow , \uparrow indicate the place and the direction (to the left or right of the original edge according its orientation) in which a new edge can be inserted. The edge symbol and sign between parentheses associated with the maker indicates the label

and orientation of the new edge ("+" if the orientation agree with the arrow, and "-" if it is opposite).

In these systems, a derivation step consists of the rewriting of all the edges surrounding a given wall (a wall means a cell in the two-dimensional case), of finding the makers pointing inwards into the wall, and of inserting one new edge if there are at least two makers with matching labels and orientation present. The insertion of a new edge is uniquely determined if there are exactly two such matching makers, and the insertion is nondeterministic if there are more than three such makers.

Definitions 1.2. An mBPMOL system is deterministic when all derivation steps are deterministic. Otherwise, an mBPMOL system is nondeterministic.

Deterministic systems are a special case of nondeterministic ones. In general, mBPMOL systems mean nondeterministic mBPMOL systems. When we need to distinguish those two systems, deterministic and nondeterministic ones are denoted by DmBPMOL and NmBPMOL systems, respectively.

We now extend mBPMOL systems as follows:

Definition 1.3. A map OL system with markers (mMOL systems) G is a quintuple $(\Sigma \cup \{\varepsilon\}, \{\downarrow, \uparrow, +, -, (,)\}, P, S, \lambda)$, where

- (1) Σ is a finite edge alphabet,
- (2) ε is the blank symbol which is not in Σ ,
- (3) P is a finite set of edge productions, which satisfies the following conditions:
Edge productions are of the form $A \rightarrow \alpha$, where A is a member of Σ and α is a sequence of $\Sigma \cup \{\varepsilon\}$ and signs, of markers and matched parentheses,
- (4) S is a starting map,
- (5) λ is the empty map.

The meaning of productions is the same to that of

Definition 1.1, except the case containing ξ . Productions containing ξ are as follows: Let the production be $A \rightarrow \xi$. Then, A is erased and two end points of A become a point. If an edge labelled A has only one vertex, then this vertex remains (if it is a part of another boundary), or it goes to λ . For two or more A 's having the same end points, this process is done nondeterministically. We give some examples of applications of $A \rightarrow \xi$.

By applications of $A \rightarrow \xi$, $B \rightarrow D^+$, $C \rightarrow E^-$ to the map of Figure 2a, we get a new map of Figure 2b. Also, by applications of the same rules to the map of Figure 3a, we get nondeterministically one of the maps shown as in Figure 3b-c. That is, one of A 's is erased and both of its ends become a vertex, and then the A disappears.

For a submap surrounding with edges labelled with A , the same situation occurs. For example (a case of existing tree edges having label A), by applications of $A \rightarrow \xi$, $B \rightarrow G^+$, $C \rightarrow H^+$, $D \rightarrow K^+$ to the map in Figure 4, we get nondeterministically one of the maps shown in Figure 5a-c.

Derivation steps of mMOL systems are also the same to mBPMOL's. A derivation step of mMOL systems consists of the rewriting of all the edges surrounding a given wall, of finding the makers pointing inwards into the wall, and of inserting new edges, if there are at least two markers with matched labels and orientation present. In this case, there may be more than one inserted if there are four or more matching markers. For instance, let Figure 6 be a configuration obtained after rewriting of all edges. From this configuration, we get one of the maps in Figure 7.

Deterministic and nondeterministic cases of mMOL systems are defined by the same way to the mBPMOL systems.

In mMOL systems, it happens that a wall disappears. An example is given as follows:

By applying production rules $A \rightarrow A^+$, $B \rightarrow B^+$, $C \rightarrow \xi$, we have the derivation represented in Figure 8. Thus, mMOL systems are generally nondeterministic and also neither binary nor

propagating.

2. Membership problem

In this section, we consider the membership problem of the mMOL systems. It has been known that the usual OL system has the decidability result for its membership problem. In contrast with this fact, the membership problem of our map OL systems with markers is recursively unsolvable. As the usual technique to prove the unsolvability, the idea used here is based on the halting problem of Turing machine. Exactly speaking, we use the result of the meeting problem of the finite causal ω^2 -systems (see [5]).

The meeting problem (A) of finite causal ω^2 -system has been given as follows:

- (A) To decide, for an arbitrary given finite causal ω^2 -system with one input symbol, whether or not it will meet with a given special state under starting from a given initial state.

In [5], we proved that this decision problem (A) is unsolvable. We use this result to prove that the membership problem of mMOL's is recursively unsolvable.

Before the proof, we give meanings of some notations used below. Let us assume that $|Q|=t$. In finite causal ω^2 -systems, all squares in the first quadrant have been given in advance. An mBPMIL system could build these squares by making use of interaction I, as mentioned in [4]. However, an mMOL system can also build those squares nondeterministically, as described below. In the following notations, h , v , u , and r correspond to "horizontal", "vertical", "upper", and "right", respectively. Also, D , E mean "odd" and "even" in the horizontal direction from the $(1,1)$ -square. As edge labels, we use quadruple (q_i, u, w, n) , (q_i, r, w, n) , $((q_i, q_j), u, w, n)$, where $i=1, \dots, t$, $w=D, E$, and $n=0, 1, 2$. As seen in the following explanation, q_i of (q_i, r, w, n) corresponds to a state q_i (of the finite causal ω^2 -system) of the under square of this edge label. Similarly, q_i of (q_i, r, w, n) corresponds to a state q_i of the left square of this edge label.

In addition to these edge labels, we use symbols such as q_0 , v_d , v_r , h_d , h_u , (v_d, n) , (h_d, n) . These meaning is possibly understood from Figure 9-14.

Lemma 2.1 One can define an mMOL system that constructs a map corresponding to the two-dimensional cell space spread over the first quadrant.

Sketch of the proof:

As exact proof of this lemma is complicated and tedious. So, we give a sketch of the proof. As mentioned before, an idea is based on simulation of a finite causal ω^2 -system in which the two-dimensional cell space is constructed. Since an mMOL system cannot get the neighboring information, it proceeds by guess.

Now, we consider an mMOL system $G = (\Sigma \cup \{\varepsilon\}, \{\downarrow, \uparrow, +, =, (,)\}, P, S, \lambda)$ satisfying the conditions:

- (1) Σ consists of all symbols which appear in Figure 9-14, and in the following P.
- (2) P consists of all rules which are necessary for derivations as shown in Figure 10-14.
- (3) S is the map shown in Figure 9.

Derivations by G are very lengthy and for this reason omitted here. The first step is shown in Figure 10a-b. Notice that, in Figure 7, q_1 of $(q_1, u, D, 2)$ and q_2 of $(q_2, u, E, 2)$ are

nondeterministically chosen. But, q_1 of $(q_1, u, D, 2)$ is determined from q_0 of $(q_0, u, D, 1)$ by the corresponding finite causal ω^2 -system and also q_2 of $(q_2, u, E, 2)$ is similarly

determined. The next step is shown in Figure 11. Then, we get the maps in Figure 12 and 13. Notice here that, in Figure 13, q_4 is determined from (q_2, q_3) by the corresponding finite causal ω^2 -system. By repeated these processes, we get the map shown in Figure 14. Therefore, we get this lemma.

The G of Lemma 2.1 could construct a map which corresponds to the two-dimensional cell space. In this case, labelling of edges simulates the state transition of the corresponding finite causal ω^2 -system. This is done by guessing. By this guessing, however, G generates also the map shown in Figure 15. We want to exclude such a map. By making use of this illegal map, we prove the following theorem.

Theorem 2.2. The membership problem for mMOL systems is recursively unsolvable.

Proof: Let us consider an mMOL system which can simulate a finite causal ω^2 -system. This is definable by making use of the mMOL system of Lemma 2.1. Because the mMOL system of Lemma 2.1 was defined such a way that its edge labels correspond to states of finite causal ω^2 -system. Here, we notice again that the mMOL system generates illegal maps. To characterize this illegal map, we extend the mMOL system of Lemma 2.1 in such a way that it generated illegal edge i_e . This illegal edge i_e is obtained by connecting between a "vertical" odd edge and a "horizontal" odd edge (or a "vertical" even edge and a "horizontal" even edge). In this case, to obtain this illegal edge the markers are put for consecutive two steps after generation of edge labelled with 0. Thus, we get an illegal edge as shown in Figure 16. Further, we extend this mMOL system in such a way that it satisfies the following conditions:

- (1) All edges except illegal edges and the special edge corresponding to the special state of the problem (A) of a finite causal ω^2 -system are erased after three steps from generation.
- (2) The special edge generates a special map and the illegal edges generate the extra maps.

This extension of the mMOL system is always possible, although the definition is complicated. Here, we consider legal map. Then, we ask if a map which contains the extra map and all other edges are erased is generated by the extended mMOL system.

Obviously, this question is equivalent to the meeting problem (A) of finite causal ω^2 -system. Therefore, we get this theorem.

3. Remark

We have proposed mMOL systems which are neither propagating nor binary. These systems seem to be interesting since they include the possibility of developmental sequences with certain walls or edges disappearance. There are further problems on relationships between the mMOL and map OL systems with other control devices than markers (e.g., those in [6]) for division determination.

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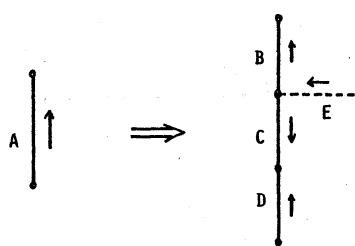
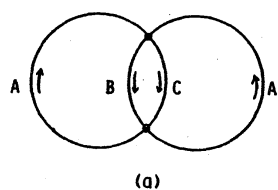
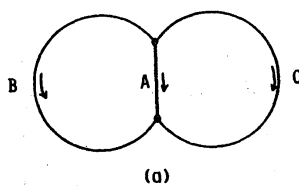


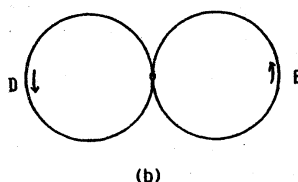
Figure 1.



(a)

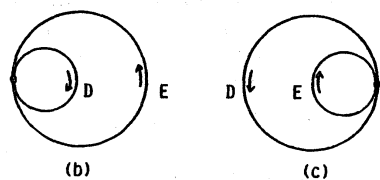


(a)

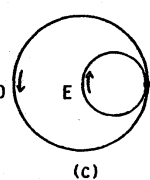


(b)

Figure 2.



(b)



(c)

Figure 3.

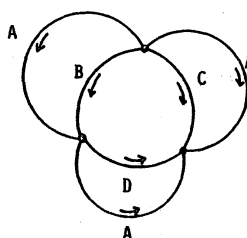


Figure 4.

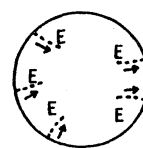
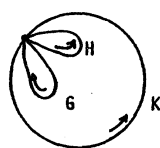
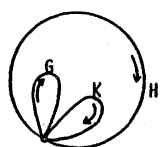
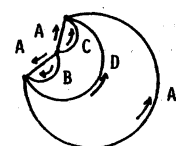


Figure 6.



(a)

This is a limit of



(b)

This is a limit of

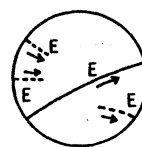
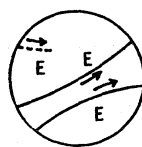
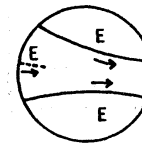
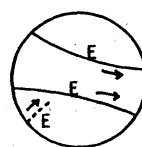
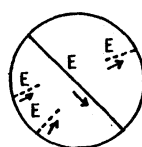
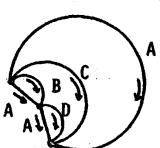
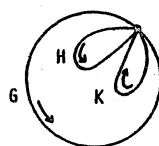


Figure 7.



(c)

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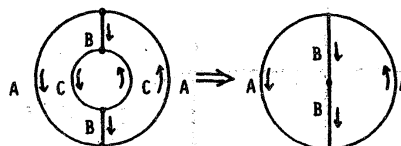
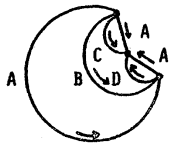


Figure 8.

Figure 5.

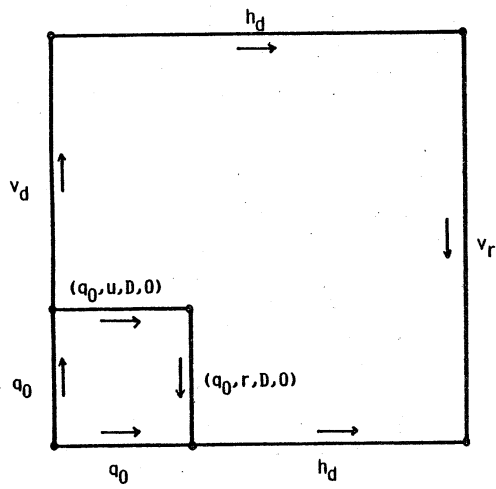


Figure 9.

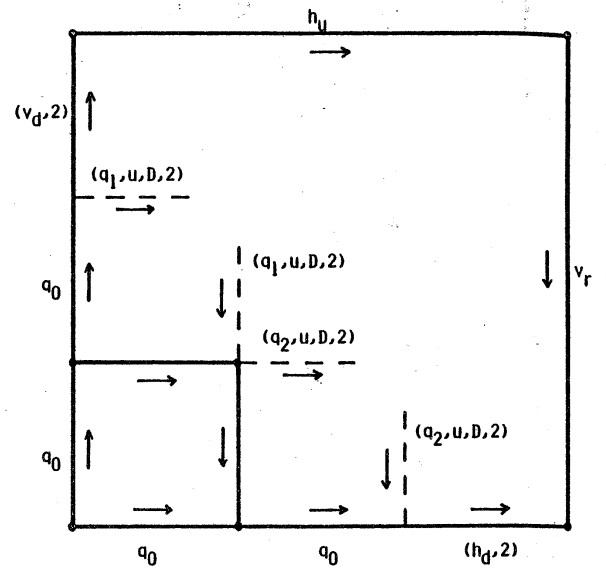


Figure 10a.

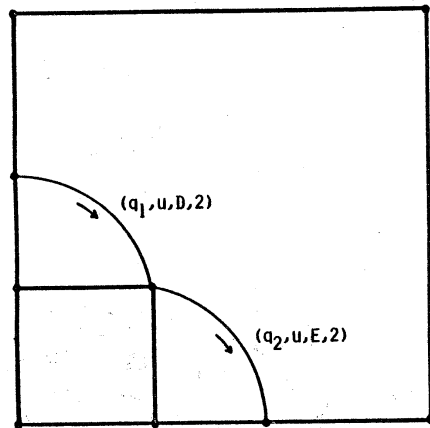


Figure 10b.

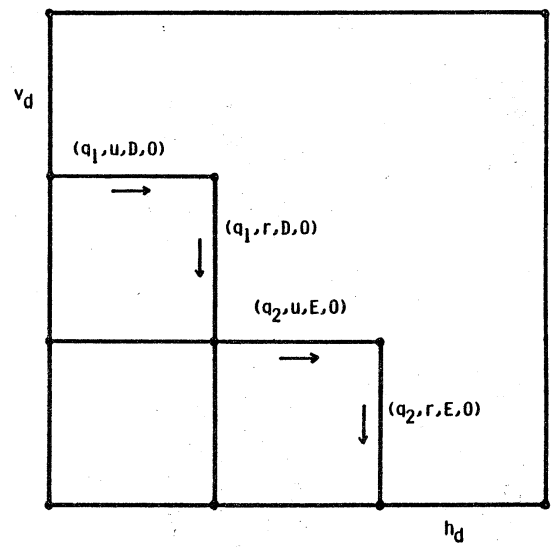


Figure 11.

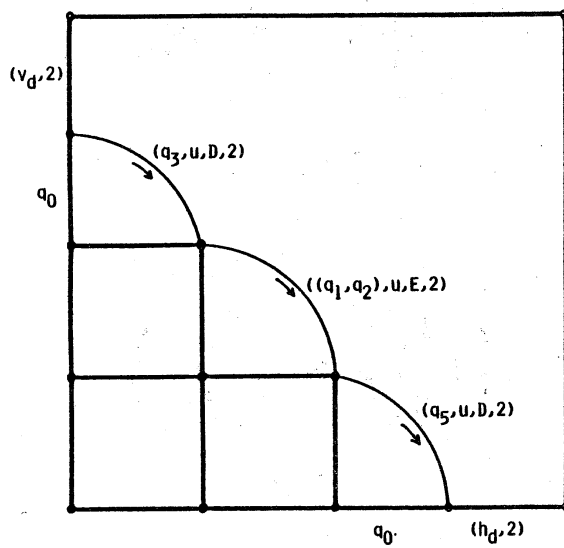


Figure 12.

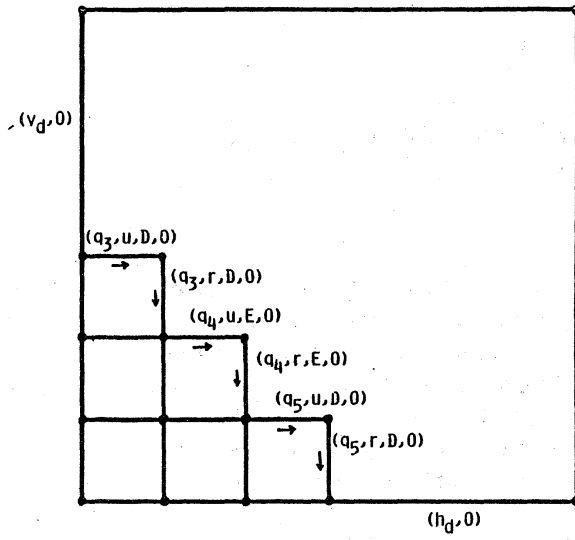


Figure 13.

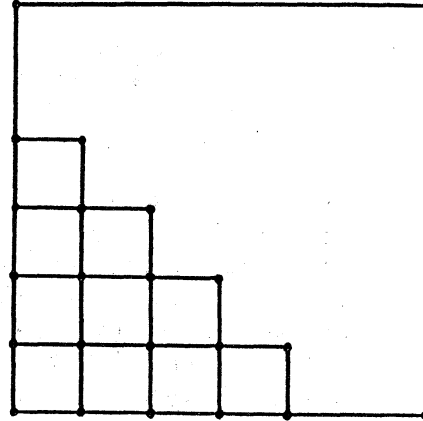


Figure 14.

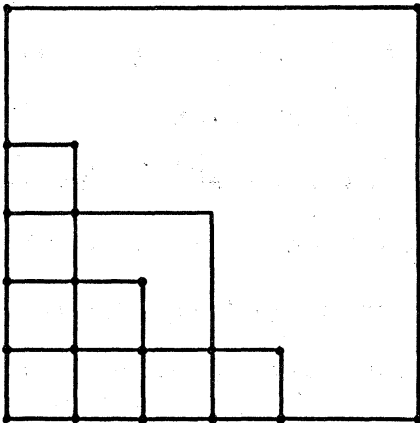
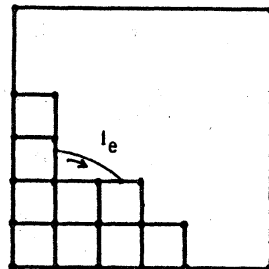
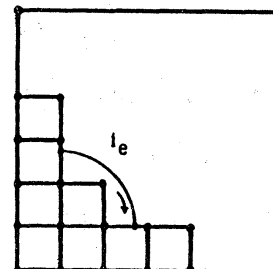


Figure 15.



(a)



(b)

Figure 16.